Origin and decline of the estuarine clam *Rangia cuneata* in the Neches River, Texas

Richard C. Harrel

Department of Biology, P. O. Box 10037, Lamar University, Beaumont, Texas 77710, U. S. A.

Abstract: The origin and decline of the brackish water clam, *Rangia cuneata* (Gray, 1831), in the Neches River were investigated by records of navigation improvements, salt water encroachment, water quality, and demographic data. The origin was probably very recent (since 1900) resulting from construction and improvements to the deep water navigation channel. These modifications formed a suitable salinity environment and allowed the planktonic larvae to be carried upriver from Sabine Lake. By 1951, after industrialization along the navigation channel, all *Rangia* beds located below river km 40.5 had been eliminated by wastewater effluents and frequent dredging. In 1971, the *Rangia* population consisted of 45 beds located between river km 40.5 and 57.3. The average density was 238 clams/m^2 and the total area of the beds was 113, 115 m^2. Since 1971, many *Rangia* beds have disappeared and all remaining beds examined exhibited decreased density to <1 to 2 clams/m^2 with an increase in average clam size. These changes were due to alterations in the river discharge pattern that decreased the frequency of salt water intrusion required for spawning and survival of larvae, and natural and cold weather mortalities. By 1985, the permitted BOD waste load in the lower river had been reduced 96%, but *Rangia* has not yet recolonized this section of the river.

Rangia cuneata (Gray, 1831) is an important estuarine bivalve (family Mactridae) that is distributed from Maryland to Florida along the Atlantic coast and from northwestern Florida to Campeche, Mexico along the Gulf of Mexico (Hopkins and Andrews, 1970; Andrews, 1971). *Rangia* is a permanent resident in the oligohaline (0.5-5 ppt) and mesohaline (5-18 ppt) regions of estuaries and is often the dominant species in terms of biomass (Odum and Copeland, 1969; Cain, 1975). *Rangia* converts organic detritus and algae into organic biomass which can be utilized by many secondary consumers, including crustaceans, fishes, water fowl, and humans (LaSalle and de la Cruz, 1985). The shells are used for construction and manufacture of many industrial products (Hopkins and Andrews, 1970; Gooch, 1971) and provide a suitable substratum for attachment of epifauna (Hoese, 1973). In addition, *Rangia* is an excellent biomonitor of some hazardous substances, including the metals cadmium, chromium, copper, and lead, as well as the chlorinated hydrocarbons dioxins and furans (Harrel and McConnell, unpub. data).

Cain (1973, 1975) and Hopkins *et al.* (1973) reported that the distribution of *Rangia* populations is due to factors that control spawning and survival of the larvae, not adult physiology. They reported that gametogenesis was stimulated by temperatures around 15°C or higher, but spawning would not occur unless salinity changed, up from low salinity or down from high salinity. If salinity change does not occur, the gametes will undergo cytolysis when the temperature decreases to about 17°C. Once spawning occurs, early larvae will not survive unless the salinity is between 2 and 10 ppt. However, after the larvae have developed past the planktonic stage and settled to the bottom, salinity is no longer a critical factor. Fairbanks (1963) reported an average life span of eight years and Hopkins *et al.* (1973) established a maximum life span of 15 years; thus, larval recruitment to populations can occur at long time intervals. Established beds of *Rangia* are concentrated where salinity seldom exceeds 18 ppt (LaSalle and de la Cruz, 1985) and have never been reported where salinity is continually higher than 15 ppt (Hopkins *et al.*, 1973).

Many investigators have reported on the distribution and abundance of *Rangia* in different estuaries and on various aspects of its physiology. These studies were reviewed by Hopkins *et al.* (1973) and LaSalle and de la Cruz (1985). However, no long term studies on a single population of *Rangia* have been conducted, but are necessary to understand how anthropogenic changes and natural environmental variations affect the distribution and abundance of the species. This study traces the environmental history, origin, and decline of *R. cuneata* in the Neches River estuary of Texas. The results substantiate information from other studies and yield new information on the ecology of this important species.

METHODS

The historical distribution of *Rangia cuneata* was postulated by correlating ecological requirements of the species with the environmental history of the Sabine-Neches estuary. Modern distribution of *Rangia* was established by locating and sampling beds along the entire length of the Neches River estuary in 1971. Individual beds were located by sighting dead shells along the shoreline and by probing the bottom with a metal rake from a small boat. When a bed was located, clams were retrieved by hand to determine if they were alive. Only live beds were studied, but the presence of dead beds was noted. The length and width of all live beds were measured and all clams from several quadrats (30.48 cm x 30.48 cm) were removed by hand for determination of density and size distribution. The number of quadrats sampled per bed varied (6 to >30) with the size of the bed and the density of the clams. The quadrats were located at various intervals along the entire length of the beds in water 30 cm to 1.5 m deep. Characteristics that delineated bed boundaries (i.e. depth, change of substratum, or physical barriers) were noted. The greatest length of all clams, or of the first 500 to 600 clams collected from the quadrats, was measured to the nearest mm with vernier calipers or with a measuring board.

Density and size distribution of clams at Bed 2, located at river km 40.5, were determined in 1969, 1971, 1977, 1978, 1981, and annually thereafter. One meter square quadrats were used during these analyses and the number of quadrats sampled varied from three during 1969, the year of highest density, to 18 in 1991, the year of lowest density. The number of quadrats sampled during other years varied from five to 15. Additional data on density and size distribution were collected at Bed 10, located at river km 48, and Bed 45, located at river km 56, in 1988 and 1992. During these analyses five 1.0 m^2 quadrats were sampled. The hand removal of clams from quadrats, as was used throughout this study, probably missed small individuals (<25 mm), and thus underestimated density. However, all collections throughout the study were conducted by the same technique and therefore reflect real changes in the population. Air temperature data were obtained from the United States Department of Commerce (1969 - 1990).

RESULTS

ENVIRONMENTAL HISTORY AND DISTRIBUTION

The occurrence of *Rangia cuneata* in the Neches River is probably very recent and can be traced with records of development of the Sabine-Neches deep water navigation channel, salt water encroachment up the river, and industrialization along the river. Kane (1959), in a study of late Pleistocene and Recent sediments, faunas, and geomorphology developed a history of the Sabine Lake-Sabine Pass area, into which the Neches River flows and where the river's parent population of *Rangia* had its origin (Fig. 1). Kane (1959) found whole shells and fragments of *R. cuneata* shells in sediments and cores from the northern and central regions of Sabine Lake and reefs of *Crassostrea virginica* (Gmelin) in the southern region. However, no salt water encroachment occurred up the Neches River prior to the deepening, widening, and shortening of the natural channel (Lower Neches Valley Authority (LNVA), 1961; U. S. Army Corps of Engineers, 1981). Thus, *R. cuneata* could not have existed in the river until development of the deep water navigation channel from the Gulf of Mexico to Beaumont, which allowed salt water encroachment and extended the distribution of *Rangia* from Sabine Lake up the Neches River (Fig. 1). Cain (1975) reported that *Rangia* larvae could be carried upstream by passive transport or by selectively swimming in the more saline water associated with flood tides.

The earliest navigation project in the Sabine-Neches system was completed in 1878 when a 3.05 m deep cut was made through the outer bank in the Gulf of Mexico (U. S.

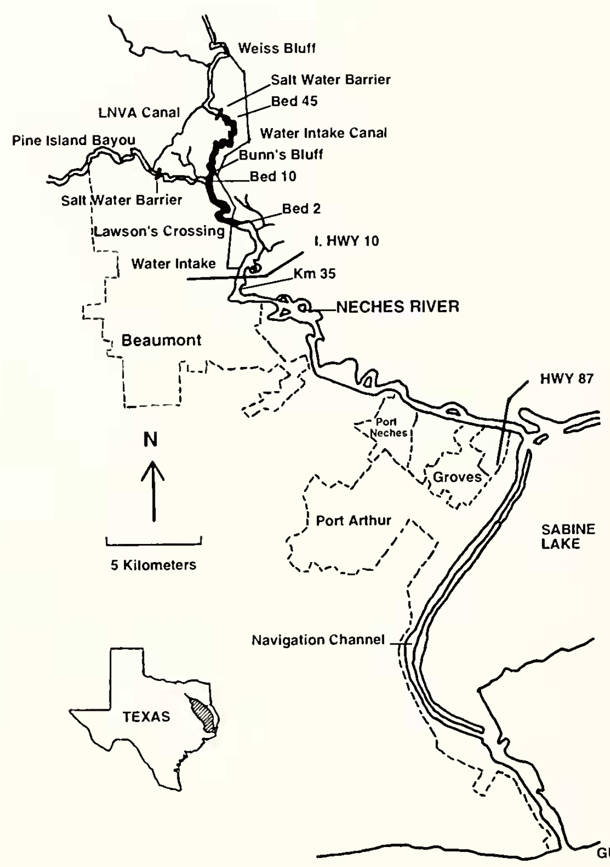

Fig. 1. Sabine-Neches estuary with locations of selected *Rangia cuneata* beds. Darkened section of Neches River channel is location of live beds.

Army Corps of Engineers, 1981). By 1900 a 7.6 m deep channel had been cut along the west bank of Sabine Lake to Port Arthur. At this time forestry, lumber milling, and rice farming were the most important features of the area economy, and navigation up the Neches River by deep-draft vessels was seasonal (U. S. Army Corps of Engineers, 1981).

In 1901, the Spindletop oil field was discovered and the trend toward oil refining and related industries spurred enlargement of existing waterways. In 1907 a 3.05 m deep channel was completed to the mouth of the Neches River and in 1914 a 7.6 m deep channel was completed to Beaumont (present day river km 35). At this time, salt water encroachment first became a problem and several pump stations on the lower river, which pumped water for irrigation of rice, had to be abandoned [Lower Neches Valley Authority (LNVA), 1961]. Also, in 1914 the Beaumont municipal water intake located at river km 36 had to be abandoned and a new intake was constructed at Lawson's Crossing (river km 41.6). In 1915 the water intake was extended upriver to Bunn's Bluff (river km 48.8) and in 1927 the city was forced to extend its canal and water intake upriver to Wiess Bluff (river km 66.7) (Fig. 1) (LNVA, 1961).

During 1924-1929 a 9.1 m deep channel was constructed to Beaumont and in 1926 the LNVA Lakeview Canal was constructed so that water for irrigation, industries, and municipalities along the lower river could be taken at river km 65.6 during periods of salt water encroachment (Fig. 1). In 1927 salt water intrusion reached the LNVA Canal and since that time, during periods of salt water intrusion, temporary sheet steel barriers have been erected across Pine Island Bayou at km 4.8 and across the river at km 60 to prevent saltwater contamination of this water supply (LNVA, 1961). Since 1932, the first year records are available, the Neches River barrier has been required during 26 years and the Pine Island Bayou barrier during 32 years. The river barrier dam diverted almost all of the flow of the river through the LNVA Canal for distribution to municipalities and industries and for irrigation of rice fields. This allowed salt water from the Gulf of Mexico and the planktonic larvae of *R. cuneata* to move up river to the Pine Island Bayou and Neches River barrier sites (Fig. 1). Additional navigation improvements that increased the frequency and duration of salt water intrusion in the river include: (1) 1937-1943 - a 10.5 m deep channel, (2) 1950 - an 11 m deep channel, (3) 1962 - a 12.2 m deep channel, and (4) 1984 - a 13.2 m deep channel (U. S. Army Corps of Engineers, 1975, 1981, 1982).

After the First World War, and especially after World War II, the petrochemical industry grew at an extremely fast rate and the lower river became grossly polluted. Most industries dumped wastes into the river without treatment turning the water black, and oil slicks degraded the shoreline (Patrick *et al.*, 1992). Whenever the salt water barrier dams were in place, salt water from the Gulf and waste effluents from the many industries along the lower river moved up to the barriers, and tidal action flushed the salt-wastewater back and forth, causing it to become more concentrated the longer the barriers were in place (Harrel, 1975; Harrel *et al.*, 1976). During many years the barriers were in place for as long as six months and the resulting pollution killed all but the most tolerant fish and invertebrates trapped below the barriers. Consequently, by 1951, the *Rangia* population in the Neches River was restricted to areas between river km 40.5 and river km 60, the saltwater barrier site (S. H. Hopkins, pers. comm., 1968). Although the upriver population had been subjected to low dissolved oxygen concentrations (<2.0 mg/1) for long time periods, it seemed to thrive (Harrel, 1975; Harrel *et al.*, 1976; Harrel and Hall, 1991).

Living *Rangia* beds had also existed in the lower river, as indicated by the presence of *Rangia* shells in the channels of the old meanders that were cut through when the navigation channel was straightened and in dredge spoils from early navigation projects. These beds were probably eliminated by dredging and toxic pollutants. Intensive surveys of this section of the river conducted by the Texas Department of Water Resources during 1969-1973 (Warshaw, 1974) and 1980 (Davis, 1984) reported 19 and 22, respectively, priority pollutants in water, sediments, or tissues at significant concentrations. These included heavy metals, phenols and cresols, polycylic aromatic hydrocarbons, phthalate esters, and general inorganics.

In 1968, when pollution abatement first began in the Neches River, the permitted biochemical oxygen demand (BOD) waste load for this section of the river was 123, 125 kg/d (220,000 lb/d), discharged primarily from oil refineries, petrochemical plants, and a large paper mill (Davis, 1984; Twidwell, 1986). The Texas Water Commission ranked the tidal Neches River as the second most polluted waterway in the state (Warshaw, 1974). Studies conducted on the tidal Neches from 1967 through 1972 examined the effects of wastewater and salt water intrusion on water quality and community structure of the macrobenthos (Harrel, 1975; Harrel et al., 1976). The results of these studies confirmed the above distribution of *Rangia*, and 45 living *Rangia* beds were located between river km 40.5 and km 57.6 (Fig. 1). An additional 19 *Rangia* beds were located in the lower 4.8 km of Pine Island Bayou, but are not included in this analysis.

In the early 1970s Federal and State regulatory agencies required all industries along the Neches estuary to upgrade their wastewater treatment systems to at least secondary treatment (U. S. Environmental Protection Agency, 1980). Since then, all wastewater treatment plants have been improved and two large regional treatment plants have been constructed. The permitted BOD waste load has been reduced 96%, to 8,717 kg/d (19,217 lb/d). Many non-BOD contributing wastes, such as heavy metals and inorganic suspended solids, were also greatly reduced. In 1986 the tidal Neches was ranked 48 of 311 classified segments (Twidwell, 1986). Harrel and Hall (1991) reported on water quality and macrobenthic community structure at the same seven collection sites before (1971-1972) and after (1984-1985) pollution abatement in the Neches River estuary. Evidence of improved water quality after pollution abatement included: (1) an increase in the annual number of taxa collected from 50 to 104, (2) minimum densities in 1984-1985 exceeding maximum densities for 1971-1972 at most stations, and (3) patterns of species dominance, Sorenson's similarity index, and Shannon's diversity index. Patrick *et al.* (1992) used the Neches River estuary for their evaluation of environmental laws on surface water quality.

During their 1984-1985 study Harrel and Hall (1991) found young *Rangia*, less than one year old, at five collecting stations located between river km 4.8 and river km 40.5. However, no mature *Rangia* have become established along the navigation channel in the lower river. This could be due to maintenance dredging of the navigation channel and frequent oil and chemical spills in this section of the river. In 1990 a bed of mature *Rangia* was located at river km 39.2, above the navigation channel, and the size of the clams indicated that this bed had been established for at least seven or eight years. During 1971 many shells but no living clams were present at this location.

DENSITY AND SIZE

During 1971, the density of the 45 live *Rangia* beds located in the Neches River varied from 16 to 665 clams/m^2 and mean density was 238/m^2. There was no correlation between density and distance upriver (r = 0.213; p = 0.078) (Fig. 2). However, mean shell length of clams significantly increased with distance upriver (r = 0.827; p = 0.0001) and lower variance occurred above Pine Island Bayou (river km 48) (Fig. 3). Ladd (1951), Gunter (1961), and Pfitzenmeyer and Drobeck (1964) reported that specimens of *R. cuneata* in fresher waters were larger than those from more saline waters, but gave no explanation. The smallest clam collected from the quadrats was 23 mm long and the largest clam was 74 mm long. The age of these specimens would be a little over one year and about 14 years, using the von Bertalanffy growth curve of Wolf and Petteway (1968). The correlation coefficient between bed density and mean clam length indicated a weak relationship (r = -0.331; p = 0.012).

The size of individual beds ranged from 42 square meters for Bed 19 at river km 53.4 to 27,360 square meters for Bed 6 at river km 44. Larger beds and higher variance were found below Pine Island Bayou, and the correlation coefficient between bed size and river km was -0.347 (p = 0.009) (Fig. 4). The boundaries of individual beds were delineated by depths greater than 1.5 m, a change in substratum from mixed substratum (sand, silty clay, and detritus) to pure substratum (sand or clay), or sunken logs, barges, or boat docks. The total area of all 45 beds was 113,115 m^2 (11.3 hectares).

Density and size data are reported for *Rangia* at Bed 2, located at river km 40.5, for 1951 from Hopkins (1970) and Hopkins and Andrews (1970) and by this investigator for 1969 to 1992 (Table 1). Hopkins (1970) and Hopkins and Andrews (1970), using data collected in 1951 and data collected by this investigator in 1969, reported that the length-frequency and density were remarkably similar and

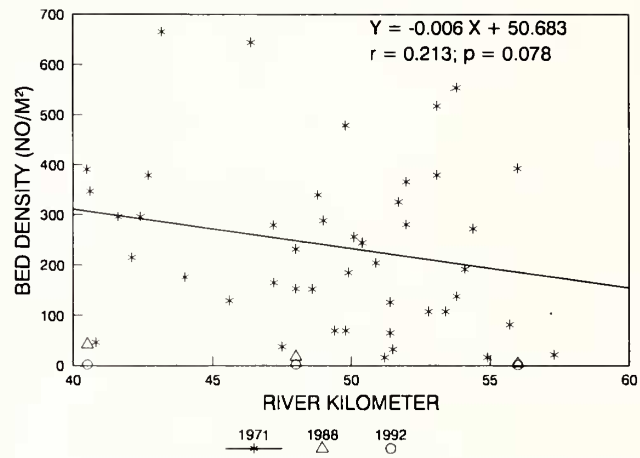

Fig. 2. *Rangia cuneata* density versus river kilometer in 1971 with best fit line, and at Beds 2, 10, and 45 in 1988 and 1992.

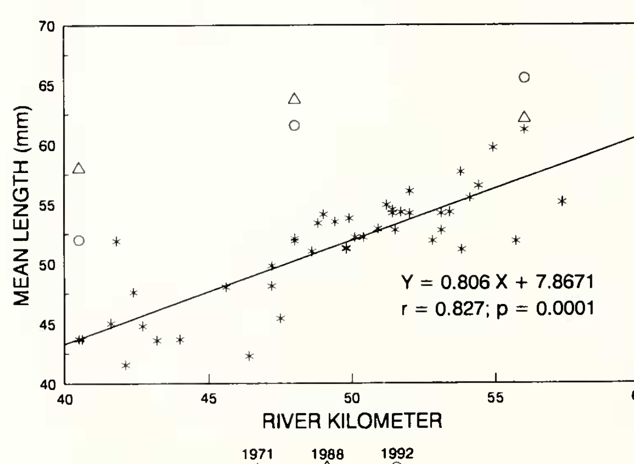

Fig. 3. *Rangia cuneata* mean shell length versus river kilometer in 1971 with best fit line, and at Beds 2, 10, and 45 in 1988 and 1992.

Table 1. Mean shell length, length extremes, and density of *Rangia cuneata* at Bed 2 in the Neches River from 1951 to 1992.

Year	Mean Length (mm)	Length Range (mm)	Density ($No./m^2$)
1951[a]	42	37 - 56	>250
1969	45	35 - 55	496
1971	44	23 - 61	391
1977	55	46 - 67	48
1978	58	34 - 67	43
1981	56	40 - 73	92
1982	53	40 - 65	141
1983	57	36 - 69	142
1984	56	40 - 67	15
1985	59	40 - 70	23
1986	58	40 - 74	22
1987	60	32 - 72	26
1988	58	45 - 69	42
1989	61	49 - 71	34
1990	59	43 - 70	2
1991	59	54 - 64	<1
1992	52	39 - 62	2

a = Data from Hopkins (1970) and Hopkins and Andrews (1970)

that the mean age of clams from both collections was between three and four years (Table 1). Hopkins (1970) reported that the density was >250 clams/m^2 during both years; although the calculated density using the 1969 data was actually 496/m^2.

Between 1969 and 1992 the mean length of clams at Bed 2 increased ($r = 0.745$; $p = 0.0006$) and density decreased ($r = -0.836$; $p = 0.0001$) (Table 1; Fig. 5). The correlation coefficient between mean shell length and bed density was -0.87 ($p = 0.001$). Data collected in 1988 and 1992 at Bed 10, located at river km 48, and Bed 45, at river km 56, indicated that these trends were occurring at all *Rangia* beds along the river (Fig. 2 and 3).

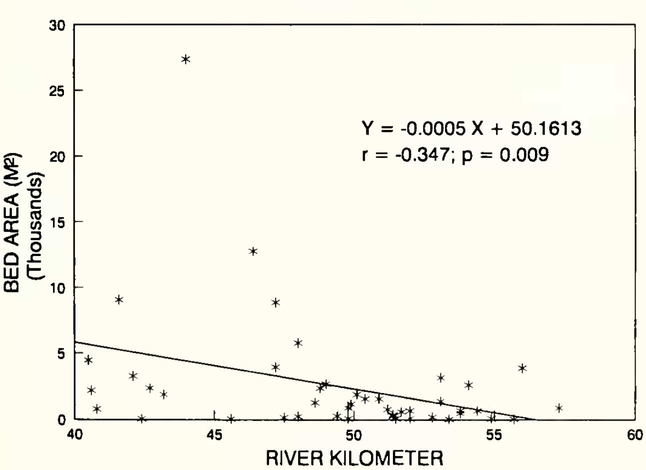

Fig. 4. *Rangia cuneata* bed size versus river kilometer in 1971 with best fit line.

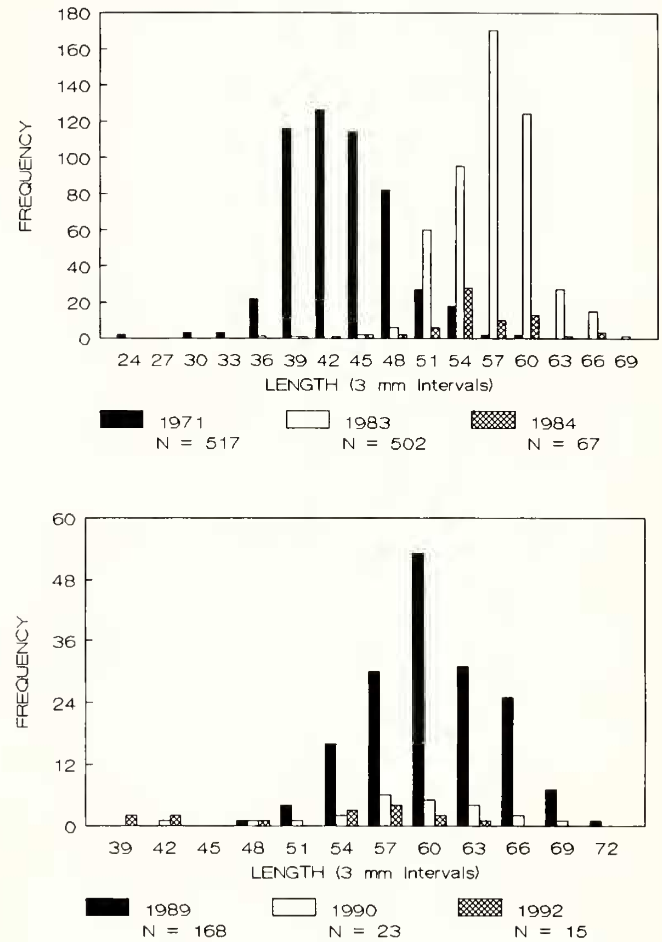

Fig. 5. Length-frequency histograms of *Rangia cuneata* at Bed 2.

The decrease in density was not constant and consisted of three years with large decreases in density (1971, 1983, and 1989) followed by several years with slight increases in density (Table 1). The sharp decreases in density between 1983-1984 and 1989-1990 resulted from high *Rangia* mortality following extreme cold fronts that occurred during December, 1983 and December, 1989. During both of these cold fronts ice formed along the shoreline and about 2 m of previously submerged shoreline was exposed due to north winds, resulting in low water levels. Two weeks after these cold fronts, the only living *Rangia* found were in water one meter or more deep, near the outer boundary of the bed where a two meter drop-off occurred. All size classes or ages of clams were affected by the cold, but the most abundant size classes had the highest mortality. The size range remained similar following both die-offs (Fig. 5). During the 1983 and 1989 cold fronts, 113 and 94 continuous hours of below freezing temperatures occurred, and new low temperature records were set (U. S. Department of Commerce, 1983 and 1989). The Texas Parks and Wildlife Department reported cold water mortalities of fish, shrimp, and crabs in many bays, coastal lakes, and estuaries along the entire Texas coast during both cold fronts. Similar cold fronts occurred during January, 1973 and January, 1976 (U. S. Department of Commerce, 1973 and 1976) and could have caused the large decrease in density between 1971 and 1977 (Table 1). However, the destructiveness of colds waves to organisms is explicable on the basis of acclimatization and depends more upon the rapidity of the temperature drop and the health of the organisms than the low temperature attained (Gunter and Hildebrand, 1951). Hopkins *et al.* (1973) reported that *Rangia* had a lower condition index (ratio of meat wet weight/internal shell volume) and meat glycogen content during November and December. This condition and time correlates with the period of major Fall spawning or cytolysis of unspent gametes, and could be the most stressful period of the year to *Rangia*. Gallagher and Wells (1969) reported a winter mortality of *R. cuneata* in the Elk River, Maryland, which is near the northernmost geographic range of the species. These are the first documented winter mortalities of *Rangia* in a Gulf of Mexico estuary.

DISCUSSION

The increase in size of clams with increasing distance upriver as occurred in 1971 (Fig. 3) and the increase in clam size at Bed 2 from 1969 through 1992 (Table 1) may be explained in terms of energy allocations for growth, reproduction, and survival during stressful times as discussed by Begon *et al.* (1990). Clams located farther downriver were more frequently subjected to salinity fluctuations that induce spawning, resulting in less energy being available for somatic growth that is beneficial for survival during stressful times. Thus, clams farther downriver would be smaller and have a shorter longevity. Likewise, clams located farther upriver could go several years without spawning, and consequently more energy can be used for growth and production of somatic biomass that could be beneficial during stressful periods and increase longevity. However, this would decrease recruitment into the population and result in a gradual increase in size and decrease in density as aging and mortalities occurred.

River discharge pattern, which effects the frequency and duration of salt water intrusion in the river, has had a profound impact on *R. cuneata* in the Neches River. Between 1951 and 1971 salt water intrusion occurred every year but one and the Pine Island Bayou salt water barrier was erected every year except 1968. The Neches River barrier was erected during 17 years of this 20 year time period. Since 1972, the Pine Island Bayou barrier was required during eight years, but only once since 1981. The Neches River barrier has been required six times since 1972, most recently in 1982. White and Perret (1974) reported that regulated river discharge from Toledo Bend Reservoir on the Sabine River had caused very low summer salinities in Sabine Lake. Freshwater flow into the Neches River estuary is controlled by releases from Sam Rayburn and Steinhagen Reservoirs, located upriver, which allow increased river discharge during summer months. Also, demands for diversion of water from the Neches River by the LNVA for irrigation of rice fields have decreased. Since 1972 the area of rice fields irrigated decreased from more than 24,281 hectares (60,000 acres) to less than 12,140 hectares (30,000 acres). Thus, time periods of salt water intrusion necessary to induce spawning of *Rangia* and suitable salinity for survival of larvae in the river have been very infrequent and of short duration during the last 20 years. The lack of recruitment and natural and cold weather mortalities have resulted in the loss of many *Rangia* beds that existed in 1971 and low densities (<1 to 2 clams/m^2) and an increased average size or age of clams at all surviving beds.

If the river discharge and cold weather trends of the past 20 years continue, *Rangia cuneata* could disappear from the Neches River. However, as pointed out by Hopkins and Andrews (1971), *R. cuneata* is a very resilient species and suitable conditions for a few years could restore the population to its former level. Also, if the third round of the U. S. Environmental Protections Agency's National Pollution Discharge Elimination System (NPDES) permit system, which began in 1987, is successful and eliminates toxic pollutants from surface waters *R. cuneata* could again become established in the lower Neches River.

ACKNOWLEDGMENTS

I thank Tommy Hebert for records on installation of the salt water barriers, Margaret O. Welch and Rolanda Alford for collection of the 1971 field data, and Thomas S. Bianchi, John T. Sullivan, and two anonymous reviewers for critical comments on early drafts of this paper.

LITERATURE CITED

Andrews, J. 1971. *Sea Shells of the Texas Coast.* University of Texas Press, Austin. 298 pp.

Begon, M., J. L. Harper and C. R. Townsend. 1990. *Ecology: Individuals, Populations, and Communities.* 2nd ed. Blackwell Scientific Publications, Boston. 945 pp.

Cain. T. D. 1973. The combined effects of temperature and salinity on embryo and larvae of the clam *Rangia cuneata. Marine Biology* 21:1-6.

Cain. T. D. 1975. Reproduction and recruitment of the brackish water clam *Rangia cuneata* in the James River, Virginia. *United States*

National Marine Fishery Bulletin 73:412-430.

Davis, J. R. 1984. Intensive survey of the Neches and Sabine Rivers Segments 0601 and 0501. Texas Department of Water Resources Report No. IS-60. TDWR, Austin. 51 pp.

Fairbanks, L. D. 1963. Biodemographic studies of the clam *Rangia cuneata* Gray. *Tulane Studies in Zoology* 10:3-47.

Gallagher, J. L. and H. W. Wells. 1969. Northern range extension and winter mortality of *Rangia cuneata. Nautilus* 83:22-25.

Gooch, D. M. 1971. A study of *Rangia cuneata* Gray, in Vermillion Bay, Louisiana. Master's Thesis, University Southwestern Louisiana, Lafayette. 48 pp.

Gunter, G. 1961. Some relations of estuarine organisms to salinity. *Limnology and Oceanography* 6:182-190.

Gunter, G. and H. H. Hildebrand. 1951. Destruction of fishes and other organisms on the south Texas coast by the cold wave of January 28-February 3, 1951. *Ecology* 32:731-736.

Harrel, R. C. 1975. Water quality and salt water intrusion in the lower Neches River. *Texas Journal of Science* 26:107-117.

Harrel, R. C., J. Ashcraft, R. Howard and L. Patterson. 1976. Stress and community structure of macrobenthos in a Gulf Coast riverine estuary. *Contributions in Marine Science* 20:69-81.

Harrel, R. C. and M. A. Hall. 1991. Macrobenthic community structure before and after pollution abatement in the Neches River estuary, Texas. *Hydrobiologia* 211:241-252.

Hoese, H. D. 1973. Abundance of the low salinity clam, *Rangia cuneata* in southwestern Louisiana. *Proceedings of the National Shellfishery Association* 63:99-106.

Hopkins, S. H. 1970. Studies on the brackish water clams of the genus *Rangia* in Texas. *Proceedings of the National Shellfishery Association* 60:5-6.

Hopkins, S. H. and J. D. Andrews. 1970. *Rangia cuneata* on the east coast: Thousand mile range extension or resurgence? *Science* 167:868-869.

Hopkins, S. H., J. W. Anderson and K. Horvath. 1973. The brackish water clam *Rangia cuneata* as indicator of ecological effects of salinity changes in coastal waters. United States Army of Corps Engineers Waterways Experimental Station, Vicksburg, Mississippi. Report No. DACW39-71-C-0007. 250 pp.

Kane, H. E. 1959. Late Quaternary geology of Sabine Lake and vicinity, Texas and Louisiana. *Transactions Gulf Coast Association Geological Society* 9:1-11.

Ladd, H. S. 1951. Brackish-water and marine assemblages of the Texas coast with special reference to mollusks. *Publications Institute of Marine Science University of Texas* 2:12-164.

LaSalle, M. W. and A. A. de la Cruz. 1985. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) - common rangia. United States Fish and Wildlife Service Biology Report 82(11.31). United States Army Corps of Engineers, TR EL-82-4. 16 pp.

Lower Neches Valley Authority. 1961. Statement on salt water barrier on Neches River below mouth of Pine Island Bayou. Submitted at public hearing by United States Army Corps of Engineers, Beaumont, Texas - November 14. 59 pp.

Odum, H. T. and B. J. Copeland. 1969. A functional classification of the coastal ecological system. *In: Coastal Ecological Systems of the United States,* H. T. Odum, B. J. Copeland, and E. A. McMahan, eds. pp. 9-86. Federal Water Pollution Control Administration, Washington, D. C.

Patrick, R., F. Douglas, D. M. Palavage and P. M. Stewart. 1992. *Surface Water Quality: Have the Laws Been Successful?* Princeton University Press, Princeton, New Jersey. 198 pp.

Pfitzenmeyer, H. T. and K. G. Drobeck. 1964. The occurrence of the brackish water clam, *Rangia cuneata*, in the Potomac River, Maryland. *Chesapeake Science* 5:209-215.

Twidwell, S. R. 1986. Intensive survey of the Neches River tidal segment 0601. Texas Water Commission Report No. IS 86-05. TWC, Austin. 92 pp.

United States Army Corps of Engineers. 1975. Final environmental statement - Maintenance dredging Sabine-Neches waterway, Texas. United States Army Engineer District, Galveston. 82 pp + appendices.

United States Army Corps of Engineers. 1981. Neches River and tributaries, saltwater barrier at Beaumont, Texas: Phase 1 general design memorandum. United States Army Engineer District, Galveston. 139 pp. + appendices.

United States Army Corps of Engineers. 1982. Sabine-Neches waterway, Texas feasibility report and environmental impact statement, channel improvements for navigation. United States Army Engineer District, Galveston, 360 pp. + appendices.

United States Department of Commerce. 1969 - 1990. Local climatological data, annual summary and comparative data, Port Arthur, Texas. National Oceanic and Atmospheric Administration Environmental Data Service. Asheville, North Carolina.

United States Environmental Protection Agency. 1980. National accomplishments in pollution control: 1970-1980, some case histories. United States Environmental Protection Agency, Washington, D. C. 153 pp.

Warshaw, S. 1974. Water quality segment report for segment 0601 Neches River tidal. Texas Water Quality Board Report No. WQS-2. TWQB, Austin. 44 pp.

Wolfe, D. A. and E. N. Petteway. 1968. Growth of *Rangia cuneta* Gray. *Chesapeake Science* 9:99-102.

White, C. J. and W. S. Perrett. 1974. Short term effects of the Toledo Bend Project on Sabine Lake, Louisiana. *In: Proceedings of 27th Annual Conference of Southeastern Association of the Game and Fish Commission,* pp. 710-721. Hot Springs, Arkansas.

Date of manuscript acceptance: 4 February 1993